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NISTIR 6527

Measurement Needs for Fire Safety: Proceedings of an International Workshop

Thomas J. Ohlemiller
Erik L. Johnsson
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National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

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Measurement Needs for Fire Safety: Proceedings of an International Workshop

Thomas J. Ohlemiller, Erik L. Johnsson and Richard G. Gann

I. Introduction

At the twelfth meeting of the FORUM for International Cooperation in Fire Research, held in Garston, England, the members agreed to convene a workshop focused on improving their capabilities in science-based fire measurements. Such measurements are at the heart of what the member organizations of the FORUM do. Whether they be inputs for fire models, fire characterization parameters for model validation, material or product fire performance, each requires careful quantification as a basis for further progress in this field.

The potential benefits of collaboration among members have long been recognized, but the complexities of transferring funds across national boundaries have proven to be a hindrance. Thus, with this Workshop, members agreed to seek an area of collaboration where each could devote internal funds toward specific mutual goals in the area of fire measurements. The Workshop was convened April 4-6, 2000 to review needs and establish common interests, thereby to converge on one or more specific inter-laboratory projects. The attendees are listed in Appendix A.

The conveners recognized that the subject of fire measurements covers a broad territory. Thus experts from various laboratories were asked to summarize their views on the needs of specific areas, including the capabilities and requirements of fire models (compartment and burning object models) and the measurements implicit in product tests and in quantifying the internal parameters of fires (heat flux, temperature, flow velocities and species concentrations). Appendix B shows the Workshop program, including the names of the invited speakers. Appendix C comprises copies of the visual aids from the invited presentations.

In the following pages, we have summarized the sense of the presentations in the various sessions of the Workshop and also the range of ideas which arose in the discussions following the presentations. Ultimately, the participants voted on the areas of primary interest for collaboration. As discussed below, heat flux measurements emerged as the main candidate.

II. Session on Capabilities of Fire Models

Tokiyoshi Yamada presented a summary of input requirements of zone-type compartment fire models and the measurement needs for model validation. Such models require initial conditions (defining the building configuration and vertical temperature profiles) and boundary conditions (wall thermal properties, the imposed heat release rate and species generation rates that mimic the burning item of interest, natural and forced ventilation flows and, in some cases, exterior wind or pressure conditions). From these inputs the models predict smoke layer height, average layer temperature and average layer species concentrations, as well as static pressure differences

between the building exterior and interior. Dr. Yamada presented desired uncertainties in all of these variables both for smoke filling modeling and smoke control design.

George Hadjisophocleous focused on fire models based on computational fluid dynamics. In general, the input requirements for initial and boundary conditions are similar to those of zone models but, if the information is available, may be more complete. For example, the complete velocity distribution at a compartment air flow inlet is desirable. In principle, these models can handle a complete computation of the test fire as well, but this is very difficult for real products of interest. Also, product yields obtained in free burn conditions and used as model inputs may not be correct in the reduced oxygen conditions of a large compartment fire. The model solutions yield complete descriptions of the space and time distributions of such variables as temperature, flow velocities and species concentrations. Because of the wealth of detail in the model output, it can be difficult to determine the extent of detailed agreement with experiment, especially if the overall character of a fire is captured but its exact behavior is not.

Vytenis Babrauskas addressed the issue of burning rate models for specific items to be found within a compartment. He first addressed items for which some correlation or approximate computational formula was available. These ranged from liquid pools to Christmas trees. Upholstered furniture models were reviewed in some detail but the point was made that these fires get geometrically very complex before they reach their peak heat release rate, making accurate modeling unlikely. Wall and ceiling-lining fire growth models have received extensive attention but appear to need further work; none has been included in a compartment fire model. For a wide variety of other real products, there are no computational formulae. The SFPE Handbook of Fire Protection Engineering [1] does include sample heat release rate data for a variety of such products; this list will expand in the revised edition now in preparation. Dr. Babrauskas called for greater attention to the spread of fire among multiple items in a room environment.

The discussion was then opened to all participants to address the most urgent measurement needs for model input, output or validation. The discussion was allowed to range rather widely with no particular attempt at convergence of opinion on measurement needs. We summarize here some of the more prominent ideas which did emerge in the discussion.

- It can be useful to insert into a fire model a sub-model of the type of sensor(s) being used in validation experiments. An example would be a sub-model of each thermocouple that includes its time response and radiation influences. This could aid the comparisons between model and experiment, but it is useful only if the sensor model is accurate.
- There is a need for an internationally accepted (and thus thoroughly validated) set of fire test data which could serve the role of model validation.
- There is room for a more thorough effort in both modeling and experimental validation. The impact of combined model input uncertainties on the model outputs has not been studied

sufficiently. Similarly, the repeatability of experiments used for model validation is not well established.

- Since all measurements contain errors, it would be useful to do a sufficient number to examine overall mass, energy and species balances, as a check on the internal consistency of the measurements.

There was also a generalized focus on species generation, reaction and transport and the need for multi-point measurements, notably in such difficult situations as a doorway after flashover. Similarly, there was general interest in heat flux prediction and measurement.

III. Session on Product Tests

Kristen Opstad discussed product tests, with a focus on those being adopted by the European Union. The tests range from a non-combustibility test whose main purpose is to define this term, i.e., when a material is subjected to an intense furnace exposure, it does not evolve a measurable amount of heat. Such a test does not provide data for fire modelers. Other tests include heat of combustion in a bomb calorimeter which provides an upper limit on the heat to be seen in a real fire. The single burning item test is used for wall or ceiling lining materials. It provides measures of heat release rate, smoke production, flame spread and tendency to produce burning droplets. The heat release rate results are cast in terms of an index based on the peak heat release rate and the time to this peak. Six classes of behavior are then defined, using fire behavior of materials in ISO 9705 as a reference. This provides some guidelines for fire protection engineers in applying the results of this test. There are also eleven new tests dealing with fire resistance. A notable addition to these is the use of a plate thermometer to measure and program furnace temperature.

Pravin Gandhi discussed product tests used in North America. There is a very wide variety of such tests whose results are used in voluntary safety standards or in building code compliance. Most are highly product-specific and do not yield outputs that a fire modeler could use in a predictive manner. In addition to tests for ignitability, combustibility and flame propagation, Dr. Gandhi discussed tests for fire detection sensitivity, for fire resistance of a wide variety of industrial fire control products and for fire suppression.

In discussing product tests in Asia, Yuji Hasemi noted that there has been no movement as yet toward regional harmonization of fire performance requirements. However, in the face of a growing fire problem in parts of the region, there is an increasing interest in applying ISO fire test standards. In most of the region there is little experience with performance-oriented tests. Japan, however, is in the midst of adopting a performance-based code for buildings. For room lining materials, this may be based on ISO 9705, with two smaller scale test alternatives under consideration: a reduced-scale enclosure test and the Cone Calorimeter. The focus of the enclosure test is likely to be toxicity assessment, however, rather than prediction of larger scale flashover potential.

In the discussion section, participants were invited to address whether they wanted to focus on a measurement method for a product or on how an existing product test method could be modified to produce data for fire models or performance-based codes. The discussion instead ranged more broadly, starting from questions and comments evoked by the morning's presentations. A few of the more prominent points made were as follows:

- There have been some large inconsistencies among various facilities in the measurement of heat fluxes, particularly in the context of fire resistance testing. There is a distinct need for a set of guidelines that would improve lab-to-lab consistency and accuracy.
- Reduced-size “room” tests results do not predict full-scale behavior because not all of the scaling parameters can be matched. The result can be qualitative differences in fire growth behavior.

There was some discussion of the toxicity of fire gases and how best to measure them, plus a call for better means to measure them in the context of a fire. It was pointed out that the Cone Calorimeter has been shown to yield quite low levels of carbon monoxide, making it a poor candidate platform for such measurements. The high levels of CO in post-flashover fire gases are evidently the result of quenched combustion chemistry, not simply low ambient oxygen levels.

IV. Session on Fire Parameter Measurements

Ned Keltner focused his presentation on temperature and heat flux issues in the context of large furnaces used for fire resistance measurements. Experience has shown that the instantaneous temperatures in different test furnaces can vary by 100 °C or more and the instantaneous heat flux can vary by a factor of two. Even thermocouples at the same location, oriented differently with respect to the heat source, can disagree by 100 °C. An extensively instrumented “furnace characterization unit” was substituted into the sample position in the furnace to provide redundant measures of heat flux to a sample. Dr. Keltner suggested that this redundant heat flux measurement approach be adapted to other, smaller fire test apparatuses.

William Grosshandler presented an overview of gas flow and gas velocity measurement issues. Duct flows are at the heart of such measurements as heat release rate. The non-spatially-resolved flow measurements typically applied to these have an uncertainty of the order of 5 %. Spatially resolved measurements are needed for validation of field model predictions of fire-induced flows. A number of traditional techniques for point flow measurement are not well adapted to fire. Particle imaging velocimetry is useful but limited in the spatial area it can measure. A related technique applies to the tracking of particles in sprinkler sprays. The areas in most need of improved flow measurements include those through openings into a compartment fire and flows near a fire plume. Optical techniques for this need hardening and larger area coverage capabilities.

William Pitts addressed the problem of temperature measurements in fires. Radiation-based methods were briefly mentioned but the primary focus was thermocouples. Errors in thermocouple measurements of local gas temperatures can be considerable, especially in compartment fires where the radiation field is highly asymmetric. Aspirated thermocouples, which are much less convenient to use, can reduce these errors substantially but not eliminate them. The use of three unshielded thermocouples of different diameters to permit extrapolation to results for zero size yields anomalies when applied to rapidly fluctuating conditions since the thermocouples have differing response times. There is a continuing need for better means to estimate the errors and uncertainties of temperature measurements in fire environments.

The ensuing discussion ranged over these three classes of measurements and the desirability of making each the focus of a collaborative effort. The issue of the time response of thermocouples and the desirability of modeling it received some discussion in light of the anomalous behavior observed by Dr. Pitts. Heat flux measurements received more interest and again the point was made that it is necessary to know the relationship between the heat flux to the burning surface in small scale tests (e.g., the Cone Calorimeter) and full-scale fire tests of real products. One or two participants pressed for further efforts on velocity measurements but there was no consensus in this direction.

It was pointed out that what regulators seek in a product test differs from what fire researchers seek. The former want consistency in the test results; the latter want information that can be generalized to predict product behavior in new situations. This arose in the context of discussions as to where the collaborative efforts should focus - on improvements in fundamental parameter measurements or on product performance factors more immediately of interest to regulatory personnel.

V. Session on Heat Release Rate and Species Measurements

Marc Janssens gave an overview of the measurement of heat release rate from burning objects. Methods based on sensible enthalpy measurement were briefly reviewed but the main focus was on oxygen consumption calorimetry. Small, medium and large-scale applications were briefly reviewed. Available uncertainty analyses were summarized. In a single laboratory, using a single well-defined fuel, uncertainty varies from $\pm 5\%$ for the Cone Calorimeter to $\pm 7\%$ for large-scale heat release rate measurements. Round robin tests among laboratories at various scales show substantially larger uncertainties. It was pointed out that one possible source of this variability among laboratories is differences in the time response of the calorimeters. This issue of time response and how it affects observed values of peak heat release rate has received little attention.

Per Blomqvist discussed extractive methods of gas analyses in fires. Gas sampling via probes inserted into a fire offers some advantages over optical methods which are degraded by soot but, at the same time, the probe disturbs the fire and one has to be sure that the sample entering the probe emerges unchanged at the other end. Analysis methods for permanent gases and less volatile species were briefly reviewed and the talk then focused on Fourier Transform Infrared

spectroscopy (FTIR). This technique has the advantage of sensitive quantitation of several species simultaneously with a response time on the order of several seconds. Response time is degraded as sensitivity is increased.

Linda Blevins surveyed several non-invasive optical techniques for species concentration determination. Unfortunately, most of these techniques, such as spontaneous Raman scattering or laser-induced fluorescence, are seriously degraded by the presence of soot, especially the heavy soot typical of real room fires. The use of tunable diode lasers is more promising and is the subject of a current NIST research project. These are used for absorption spectroscopy and, as such, are somewhat invasive since localized species absorption measurements require the introduction into the fire environment of a platform having the diode laser and a detection cell. The technique offers promise of detection of a wide variety of species but some significant technical challenges remain.

George Mulholland discussed smoke aerosol measurements. Such measurements are needed for improved detection of fires, product characterization, validation of smoke dispersion models and for sub-grid modeling of flame radiation. Typical uncertainty levels (95 % confidence limits) for smoke concentration when sampled from a duct are ± 10 % but no time resolution is obtained. Time-resolved smoke yield measurements require a technique like optical extinction. As applied in the new NIST Furniture Calorimeter, such a smoke meter is capable of an expanded uncertainty (2σ) of about ± 20 %. Smoke sampling in flames is more complex, spatial gradients are large and uncertainty levels for various available techniques have not been assessed. There remains a need for a round robin on soot measurement using a standard generator.

VI. Selection of a Topic for Collaborative Work Among FORUM Members

With the completion of the prepared presentations, the discussion turned to the selection of the one (or more) topic(s) of greatest opportunity for collaborative work. All attendees were asked to state their preference as to the single topic area that they viewed as being most needed and most promising in this regard. Polling of the attendees elicited subjects from CO measurements in room fire conditions to velocity measurements in fire plumes or at room openings to measurements of the yield of respirable aerosol particles. There was considerable discussion of whether any collaborative effort should focus on the same overall test environment (e.g., the ISO 9705 room) with differing measurands at each lab or whether all labs should focus on the same measurand within such a room context.

The latter approach prevailed. The most frequently mentioned needs were improvements in measurement of:

- Heat flux to the surface of a burning sample
- Gas velocity over spatial areas in a room fire environment
- Temperature over areas in a room fire environment
- Heat release rate from full-scale burning objects
- Smoke characteristics

When the attendees were asked to vote for their preference on the above list (with the understanding that their laboratory would likely participate in an effort in the expressed area of interest), heat flux emerged as the top choice.

Heat flux is at the heart of burning rate and fire growth in a compartment environment. It is thus of primary importance. The measurement challenge ranges from the mainly radiant fluxes at floor level, to combined radiant and convective fluxes during fire growth and, finally, during burning. In this last area, particularly, it is essential to demonstrate that the sample surface is subject to the same heat fluxes in bench scale tests as seen in full-scale room fires. There were repeated suggestions that multiple methods of heat flux measurement be applied to these problems but no clear consensus on this issue emerged. There was repeated emphasis by several participants on making a room corner test configuration the focal point of heat flux measurements.

The group then discussed a set of goals for the proposed joint measurement effort. The three general goals which emerged are:

- To quantify the level of uncertainty in such measurements as well as the sensitivity of the measurements to the parameters known to affect them,
- To reduce these uncertainties to a point where there is general agreement as to the value and usefulness of the measurements,
- To harmonize the best procedures for such heat flux measurements; this would be expressed in the form of a set of written guidelines.

The need now is for a detailed plan of action toward achieving these goals. It is to include a set of specific tasks and the laboratories responsible for each. The first meeting of the personnel from each laboratory who will be most directly involved in the work has been tentatively scheduled to take place in London in a late July time frame.

There was also interest in pursuing collaborative efforts on two of the other topics mentioned above. Marc Janssens will take the lead in the next steps on improvement of the measurement of heat release rate from room fires. Tokiyoshi Yamada will take the lead on velocity field measurements. No champion emerged in the topic area of temperature distribution measurements.

Acknowledgments

FORUM members kindly consented to providing a venue for the organization of a workshop on collaborative fire measurements. Richard Bukowski of NIST helped move this issue to the forefront of international interaction. Richard Gann served as discussion leader throughout this Workshop.

References

[1] SFPE Handbook of Fire Protection Engineering. 2nd Edition. National Fire Protection Assoc., Quincy, MA, DiNenno, P. J.; Beyler, C. L.; Custer, R. L. P.; Walton, W. D., Editor(s), 1202 p., 1995.

Appendix A - FORUM Workshop Attendance List

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Appendix A - FORUM Workshop Attendance List

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APPENDIX B. Schedule of FORUM Workshop on Measurement Needs for Fire Safety

Day	A.M. (9:00-12:30)	P.M. (1:30-5:00)
Tue, Apr 4		1:00-4:30 Tuesday only Welcoming remarks (J. Snell, NIST – United States) Opening remarks (R. Gann, NIST – United States) Presentations on capabilities of Fire Models: Zone Models (T. Yamada, National Research Institute of Fire and Disaster –Japan) CFD Models (G. Hadjisophocleous, National Research Council of Canada) Burning Item Models (V. Babrauskas, Fire Science and Technology, Inc. - United States) [Group discussion of key measurements needed for (a) input and (b) validation, the accuracy and spatial/temporal resolution desired]
Wed, Apr 5	Presentations on product tests: Europe (K. Opstad, SINTEF Civil and Environmental Engineering – Norway) North America (P. Gandhi, Underwriters Laboratories, Inc. – United States) Asia (Y. Hasemi, Building Research Institute – Japan) [Group discussion of the potential of existing pass/fail test methods to provide additional product performance information]	Presentations on property measurements (accuracy, spatial & temporal resolution): Heat Flux (N. Keltner, Ktech Corporation – United States) Flow/Velocity (W. Grosshandler, NIST – United States) Temperature (W. Pitts, NIST – United States) [Group discussion to identify those types of information that are most desirable to characterize product and/or model performance]
Thu, Apr 6	Presentations on species measurements (accuracy, spatial & temporal resolution): Heat Release Rate (M. Janssens, Southwest Research Institute – United States) Gases – extractive (P. Blomqvist, SP Swedish National Testing and Research Institute – Sweden) Gases – In-situ (L. Blevins, NIST – United States) Aerosols (G. Mulholland, NIST – United States) [Group identifies those types of information that are most desirable to characterize product and/or model performance]	Identification of core measurements and best subject(s) for initial development. Identification of small Working Group of people from organizations that would perform the research

Appendix C: FORUM Workshop Presentations

SESSION I.

CAPABILITIES OF FIRE MODELS

Appendix C: FORUM Workshop Presentations

SESSION II.

PRODUCT TESTS

Appendix C: FORUM Workshop Presentations

SESSION III.

PROPERTY MEASUREMENTS (ACCURACY, SPATIAL AND TEMPORAL RESOLUTION)

Appendix C: FORUM Workshop Presentations

SESSION IV.

SPECIES MEASUREMENTS (ACCURACY, SPATIAL AND TEMPORAL RESOLUTION)

<p>U.S. Department of Commerce National Institute of Standards and Technology</p> <p style="font-size: 1.2em; font-weight: bold;">Manuscript Review and Approval</p> <p>Attach Original of this Form to One Copy of Manuscript and Send to WERB Secretariat, Mail Stop 2551 (NN/519)</p>		<p>(ERB Use Only - Version 2.10)</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; padding: 2px;">ERB Control Number</td> <td style="width: 50%; padding: 2px;">Division</td> </tr> <tr> <td style="padding: 2px;">Publications Report Number</td> <td style="padding: 2px;">Category Code</td> </tr> <tr> <td style="padding: 2px;">Publication Date</td> <td style="padding: 2px;">No. Printed Pages</td> </tr> <tr> <td style="padding: 2px;">HOLDREC# 3167</td> <td style="padding: 2px;">Changes Required</td> </tr> </table>		ERB Control Number	Division	Publications Report Number	Category Code	Publication Date	No. Printed Pages	HOLDREC# 3167	Changes Required		
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<p>Author(s) (Last Name, First Initial, Second Initial)</p> <p>Ohlemiller, T J (Primary) ; Johnsson, E L ; Gann, R G</p>		<p>Performing Organization:</p> <p>NIST/GAITHERSBURG</p>											
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<p>Abstract (A 2000-character or less factual summary of most significant information. If document includes a significant bibliography or literature survey, cite it here. Spell out acronyms on first reference.)</p> <p>At the twelfth meeting of the Forum for International Cooperation in Fire Research, held in Garston, England, members agreed to convene a workshop focused on improving their capabilities in scientifically-based fire measurements as a basis for further progress in the field of fire research. With this Workshop, members agreed to seek an area of collaboration where each could devote internal funds toward specific mutual goals in the area of fire measurements. The Workshop was convened to review needs and establish common interests, thereby to converge on one or more specific inter-laboratory projects. Experts from various laboratories were asked to summarize their views on the capabilities and needs of specific areas which included fire models (compartment and burning object models), product tests and in quantifying the internal parameters of fires (heat flux, temperature, flow velocities and species concentrations). In the following pages we have attempted to summarize the sense of the presentations in the various sessions of the Workshop and also to convey the range of ideas which arose in the discussions following the presentations. Ultimately, a vote was held among the participants as to the areas of primary interest for collaboration. Heat flux measurements emerged as the main candidate.</p>													
<p>Supplementary Notes</p>													
<p>Key Words (Maximum of 9; 28 characters and spaces each; Alphabetic order; Capitalize only proper names)</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; padding: 2px;">1. fire research</td> <td style="width: 50%; padding: 2px;">2. fire measurements</td> </tr> <tr> <td style="padding: 2px;">3. fire models</td> <td style="padding: 2px;">4. model validation</td> </tr> <tr> <td style="padding: 2px;">5. product tests</td> <td style="padding: 2px;">6. international cooperation</td> </tr> <tr> <td style="padding: 2px;">7. measurement improvement</td> <td style="padding: 2px;">8. scientific collaboration</td> </tr> <tr> <td style="padding: 2px;">9. fire science</td> <td></td> </tr> </table>				1. fire research	2. fire measurements	3. fire models	4. model validation	5. product tests	6. international cooperation	7. measurement improvement	8. scientific collaboration	9. fire science	
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